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(54) ACTIVE CLEANING VACUUM SYSTEM AND METHOD

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(22) Filed: **Mar. 15, 2019**

(65) **Prior Publication Data**

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(51) **Int. Cl.**

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C30B 23/00	(2006.01)
C30B 25/14	(2006.01)
C30B 27/02	(2006.01)
C30B 29/16	(2006.01)

(52) **U.S. Cl.**

CPC ***C30B 35/007*** (2013.01); ***C30B 23/00*** (2013.01); ***C30B 25/14*** (2013.01); ***C30B 27/02*** (2013.01); ***C30B 29/16*** (2013.01); ***C30B 35/002*** (2013.01)

(58) **Field of Classification Search**

CPC C30B 35/007; C30B 35/002; C30B 23/00; C30B 25/14; C30B 29/06; C30B 29/16

See application file for complete search history.

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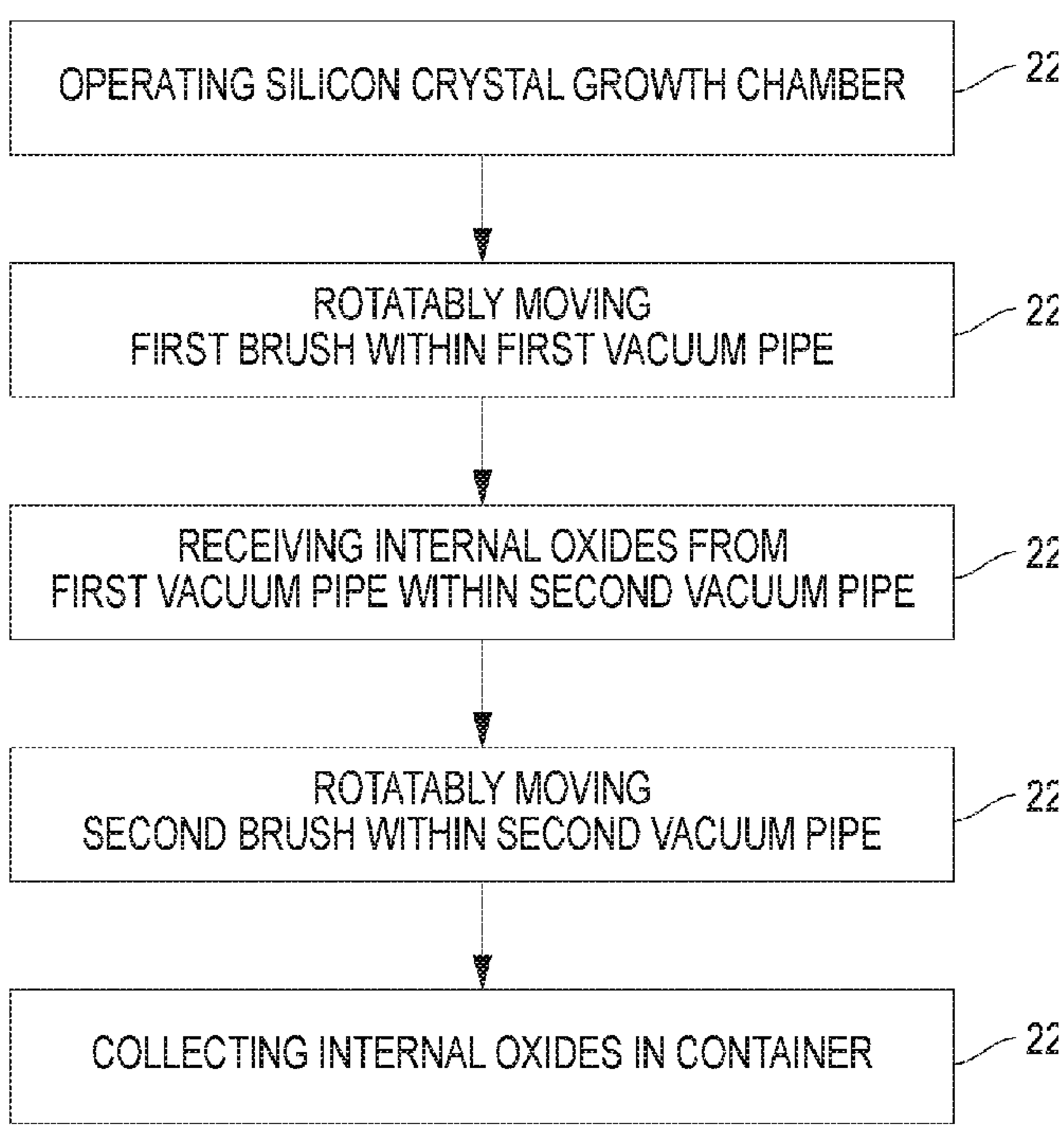
(57) ABSTRACT

A vacuum system for silicon crystal growth includes a silicon crystal growth chamber, a first vacuum pipe, a second vacuum pipe, and an oxides container. The first vacuum pipe is coupled to the chamber and has within a first brush that is movable in a first direction for removing internal oxides. The second vacuum pipe is coupled to the first vacuum pipe for receiving the internal oxides via the first brush and has within a second brush that is movable in a second direction different from the first direction. The second brush transports the received internal oxides away from the first vacuum pipe. The oxides container is coupled to the second vacuum pipe for receiving the internal oxides via the second brush.

20 Claims, 15 Drawing Sheets



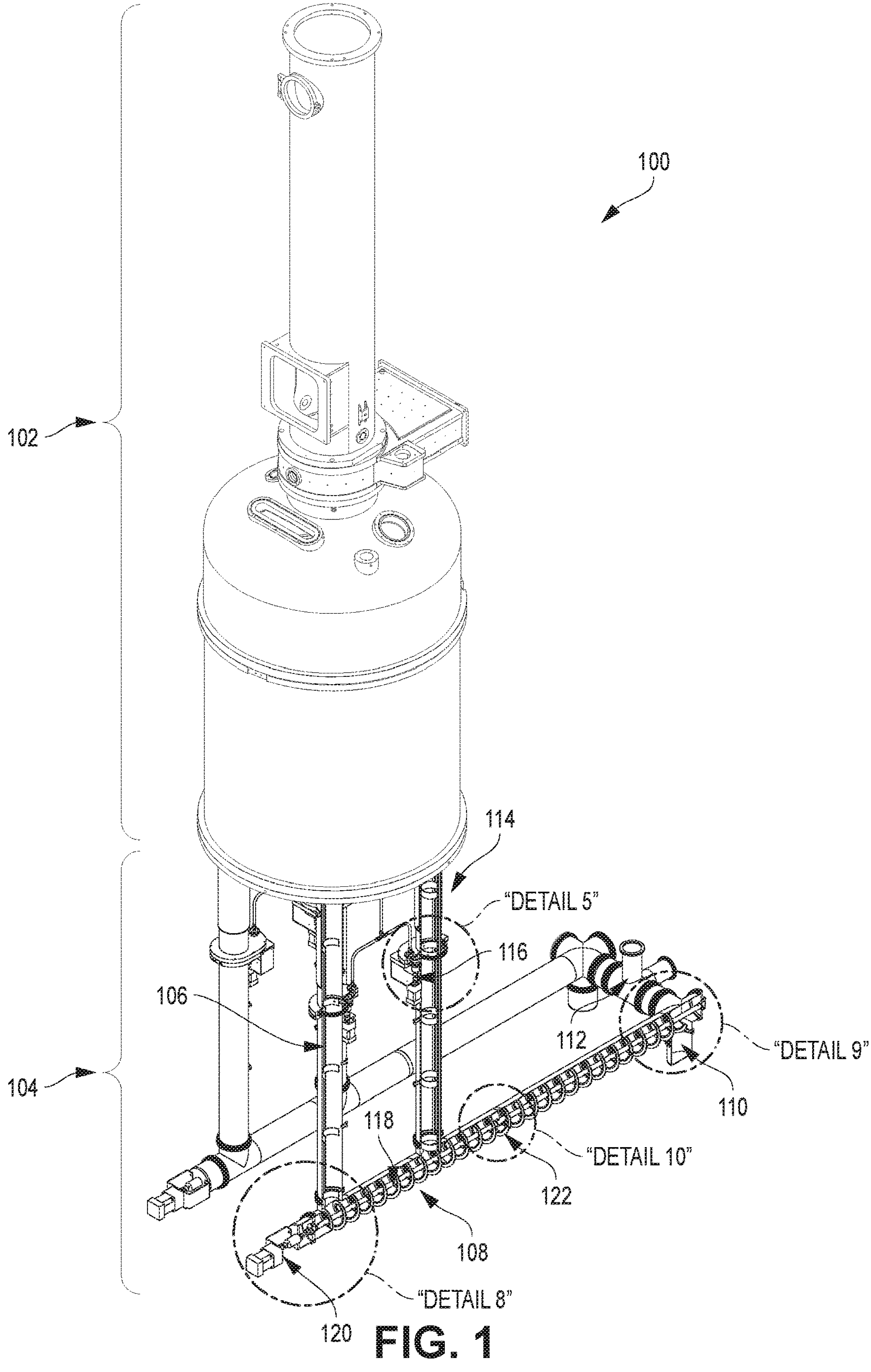
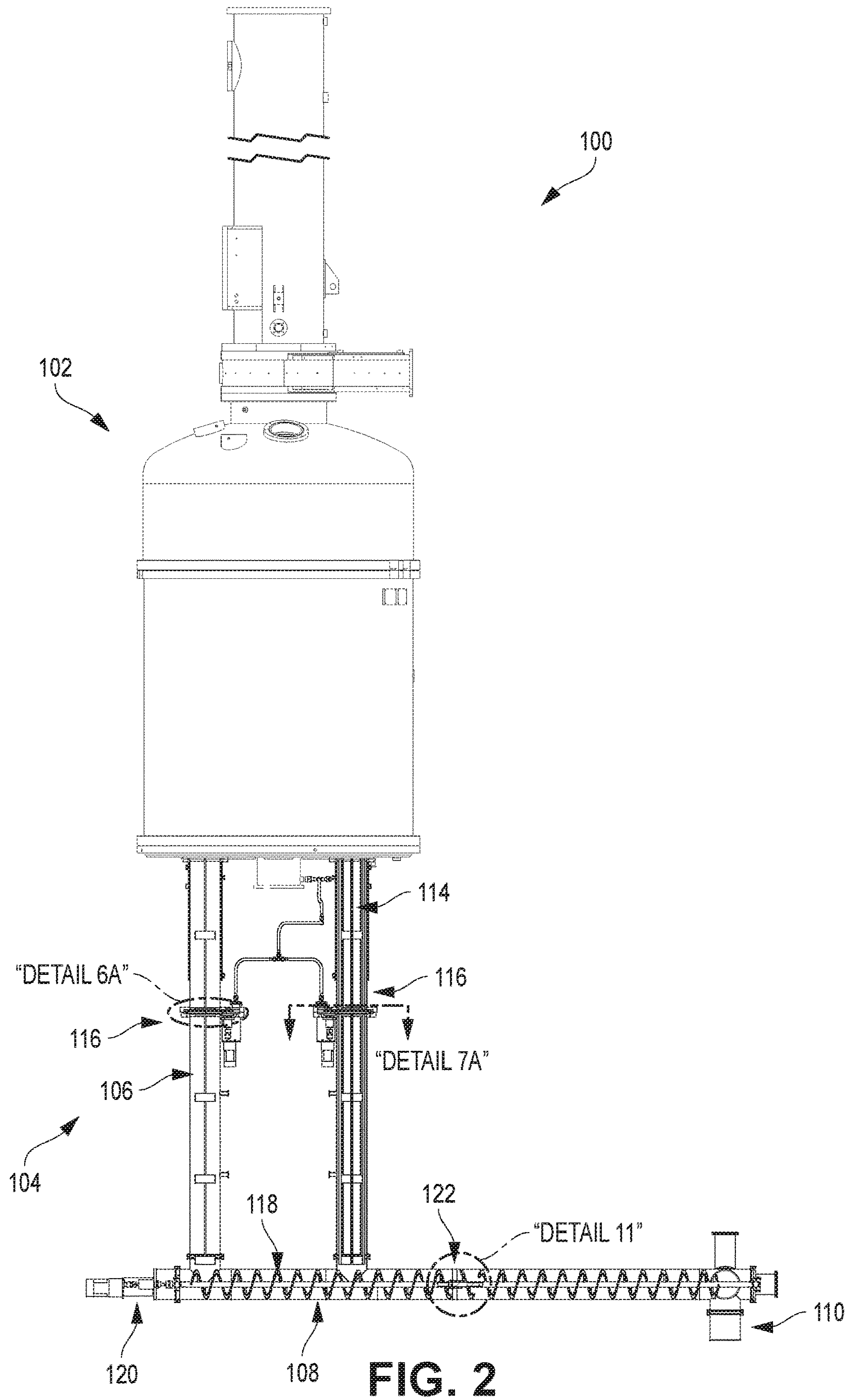

100
102
104
114
"DETAIL 5"
116
106
112
"DETAIL 9"
110
118
"DETAIL 10"
122
108
"DETAIL 8"
120

FIG. 1


100
102
114
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116
116
"DETAIL 7A"
106
104
118
122
"DETAIL 11"
110
120
108

FIG. 2

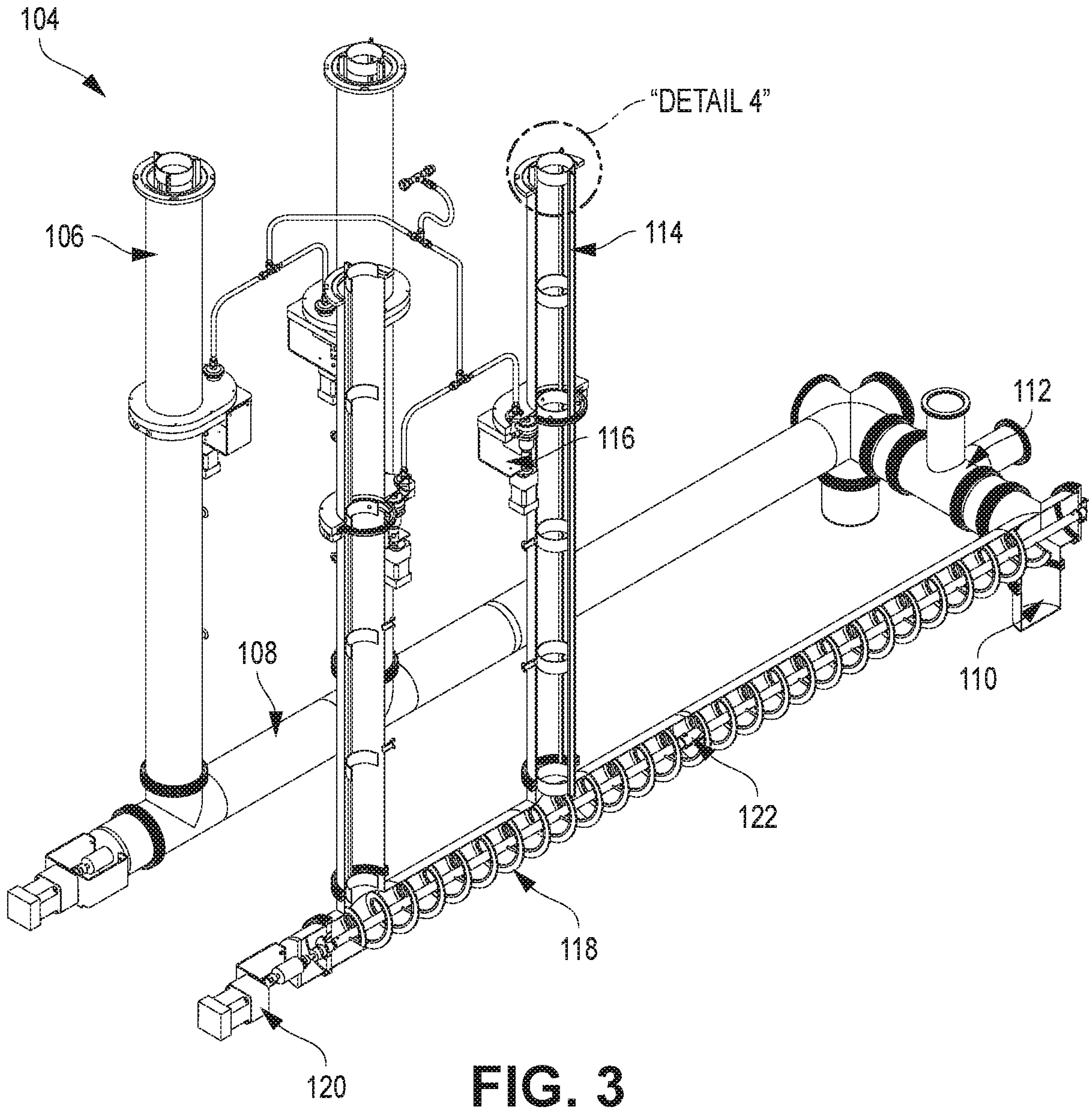

FIG. 3

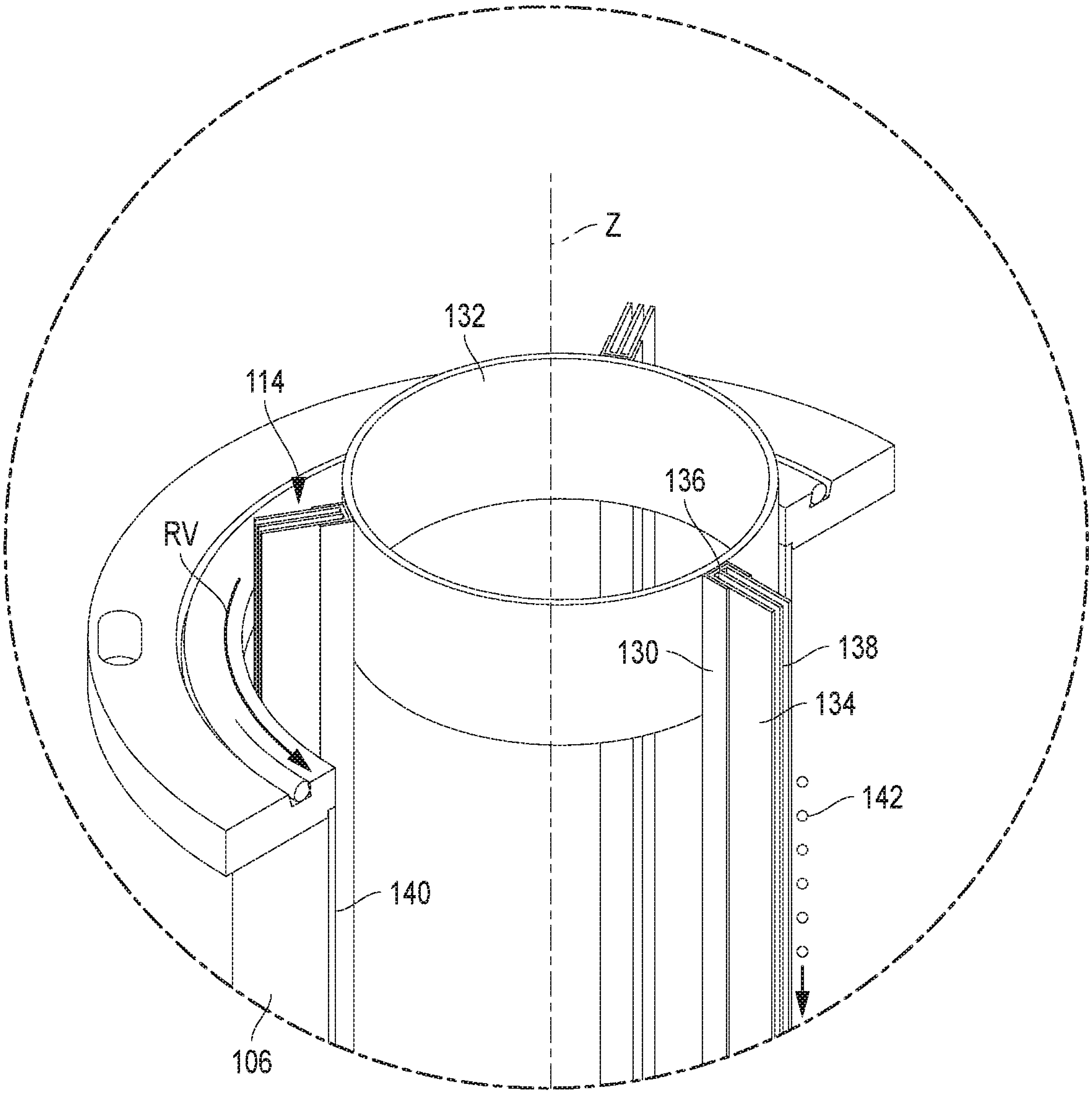

FIG. 4

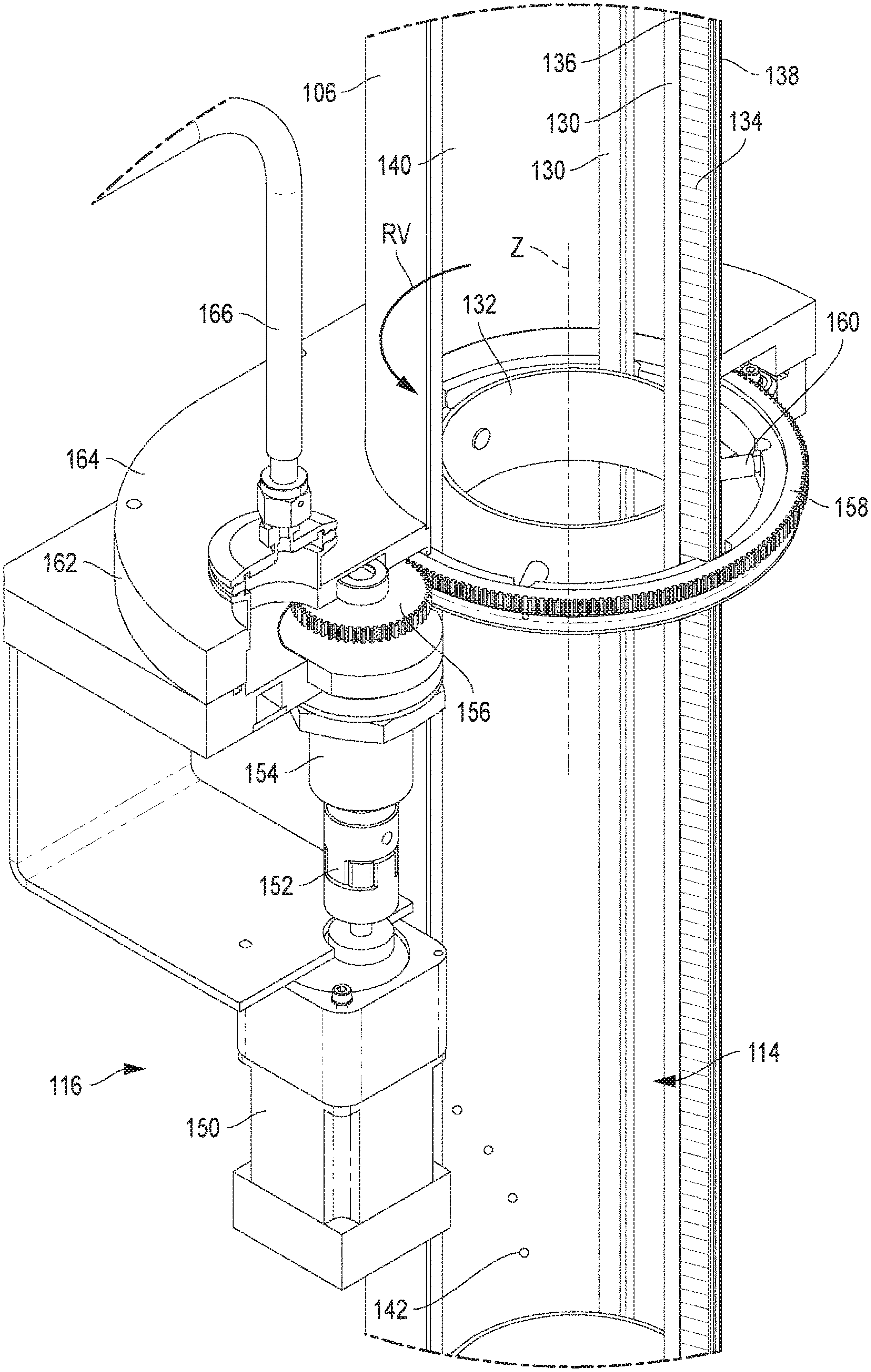
136
138
106
130
134
140
130
RV
Z
132
166
160
164
158
162
156
154
152
114
116
150
142

FIG. 5

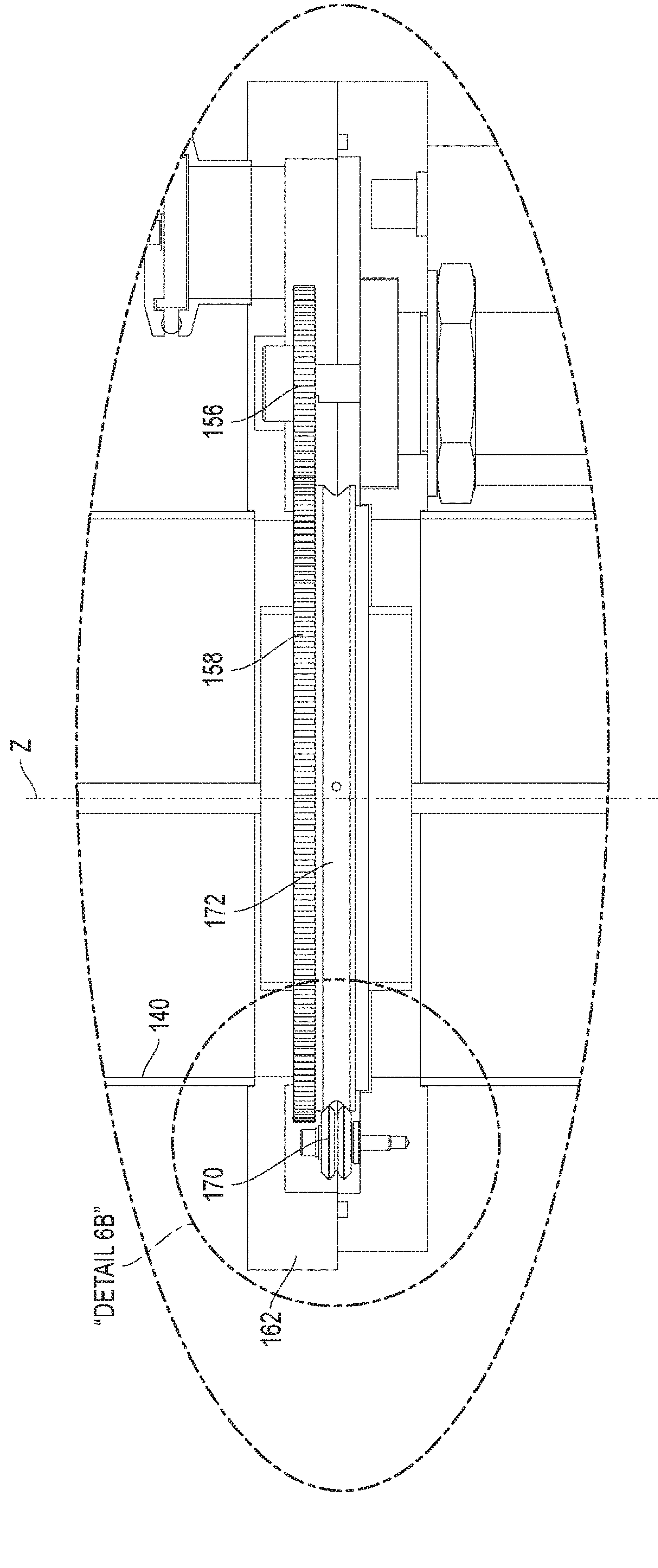

FIG. 6A

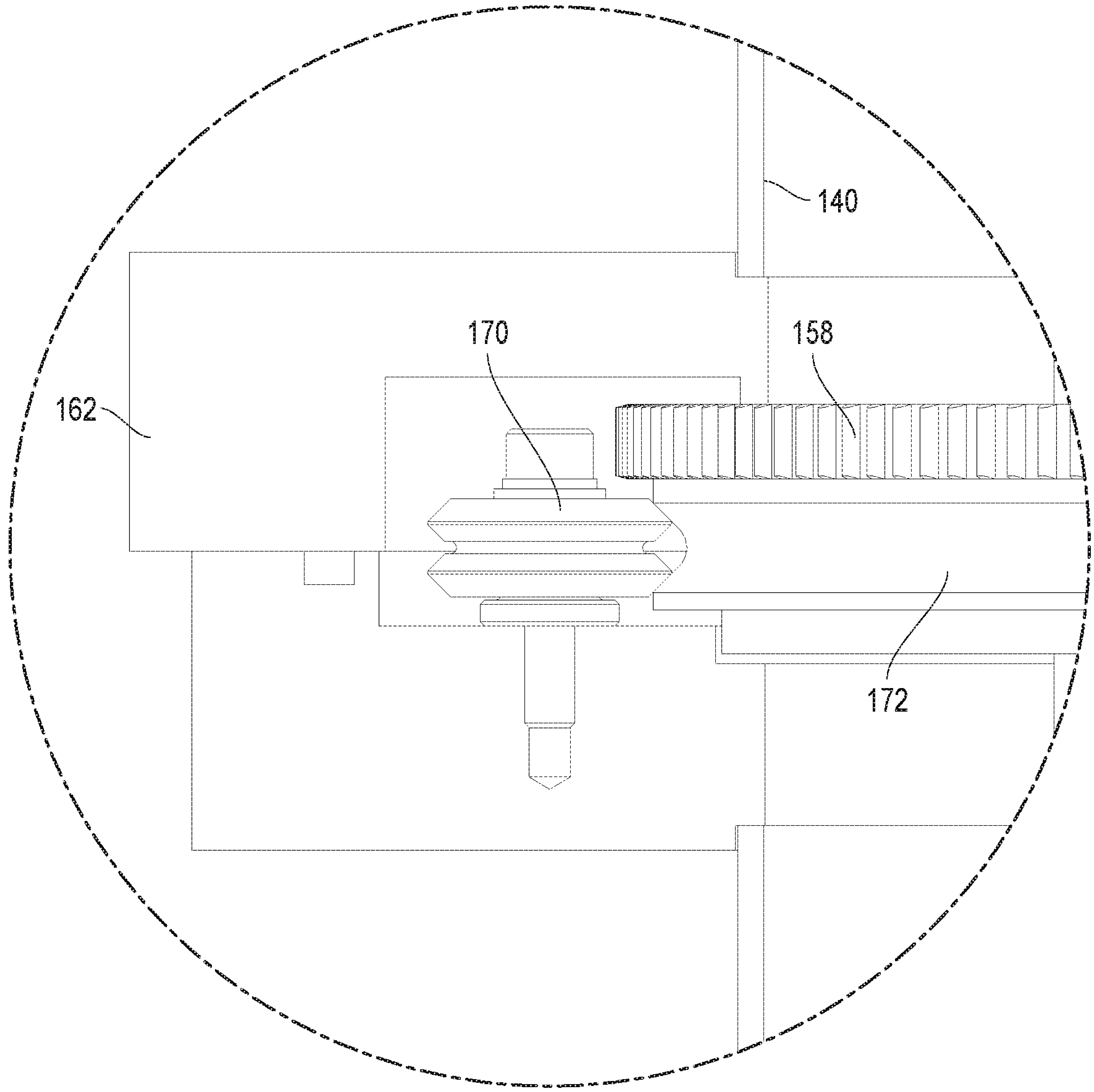

FIG. 6B

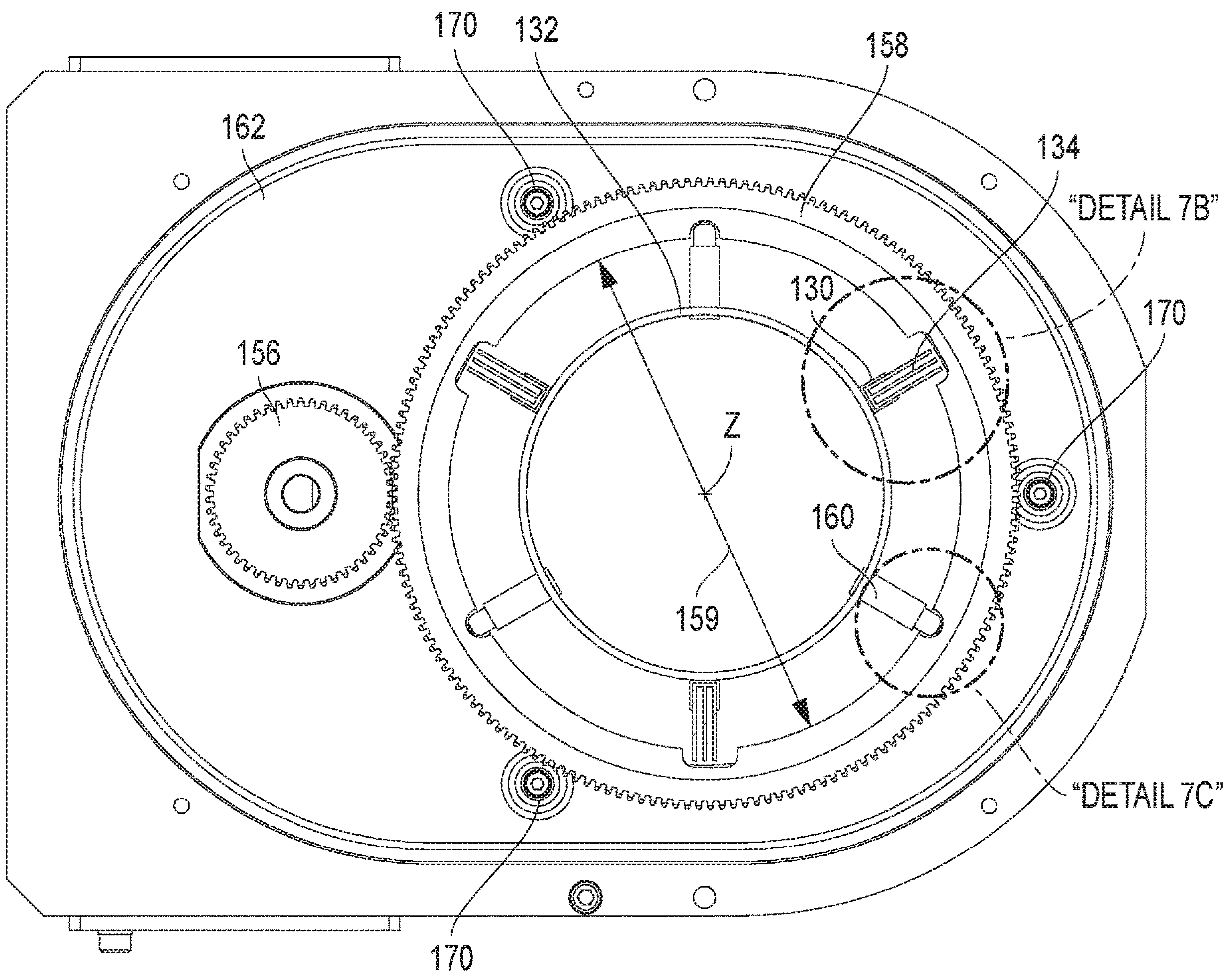
170
132
158
162
134
"DETAIL 7B"
130
170
156
Z
160
159
"DETAIL 7C"
170

FIG. 7A

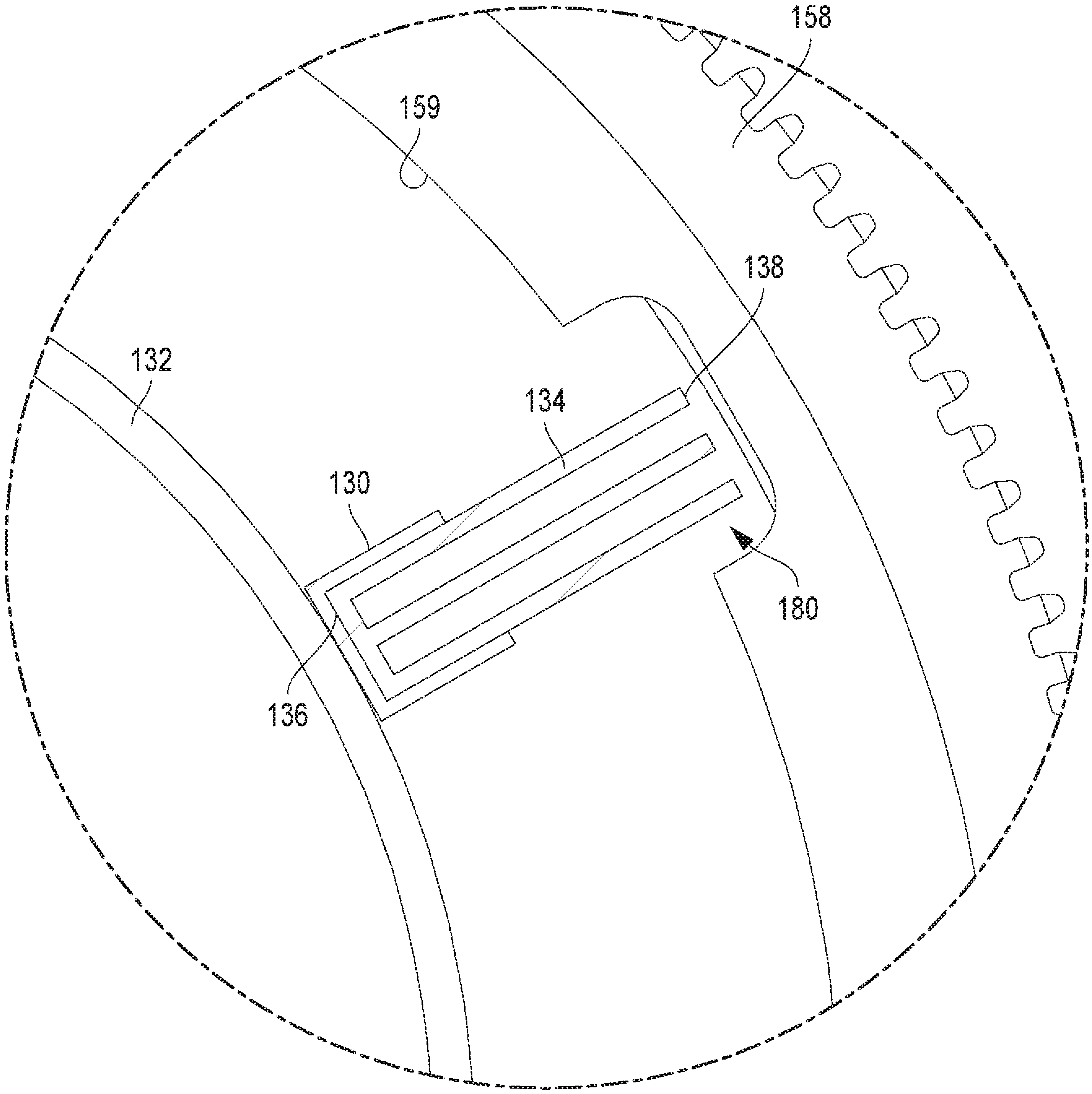

FIG. 7B

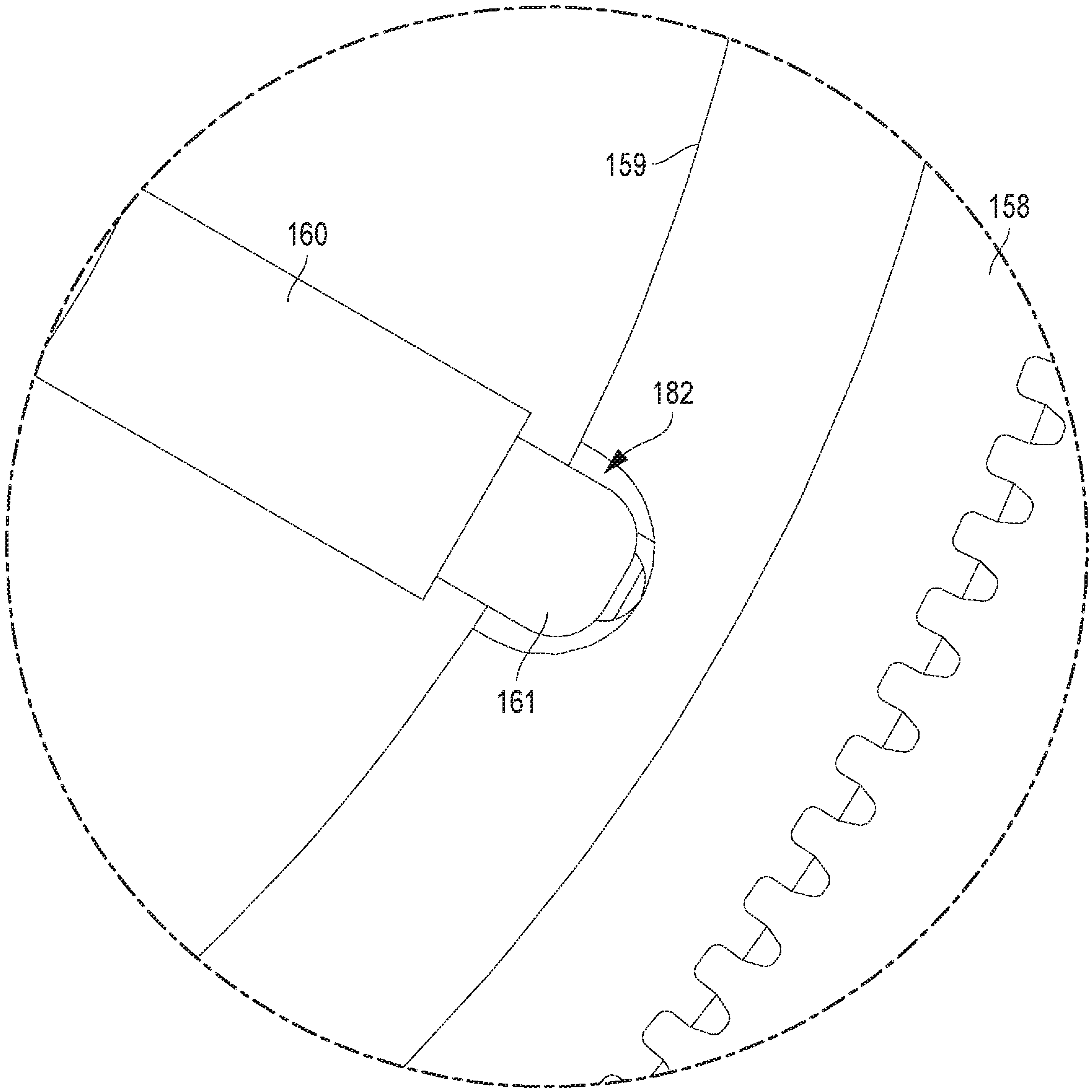

FIG. 7C

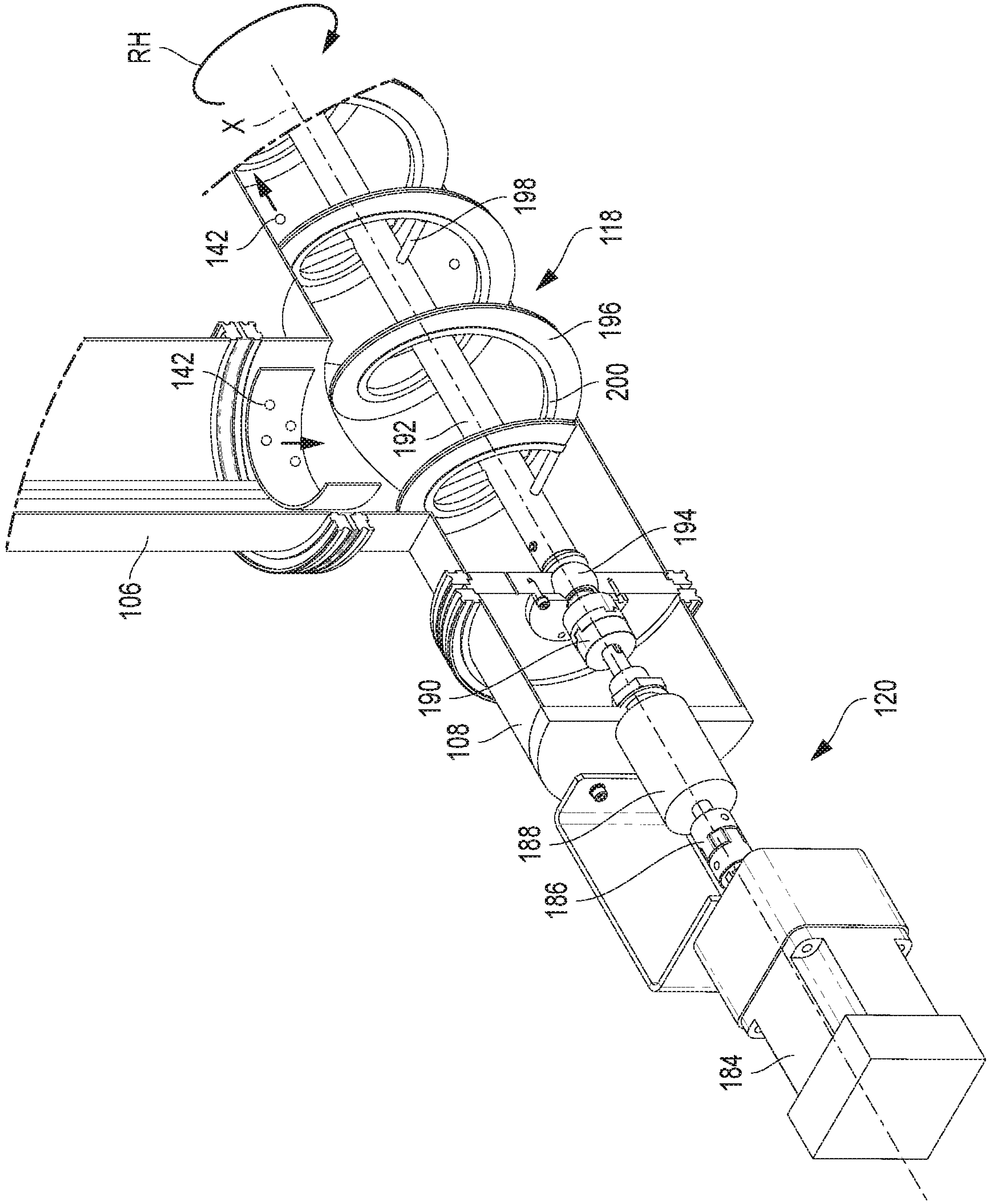

FIG. 8

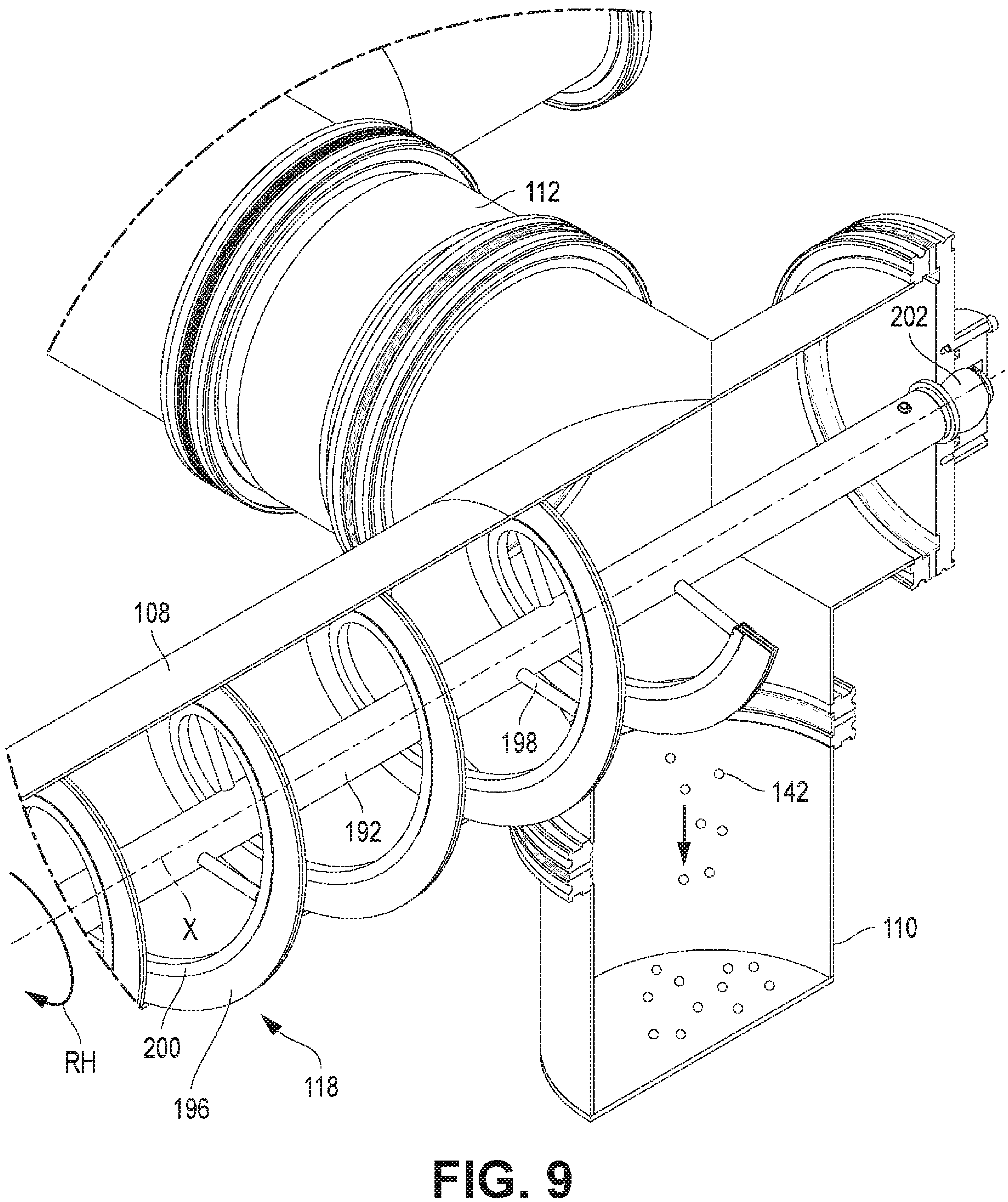

FIG. 9

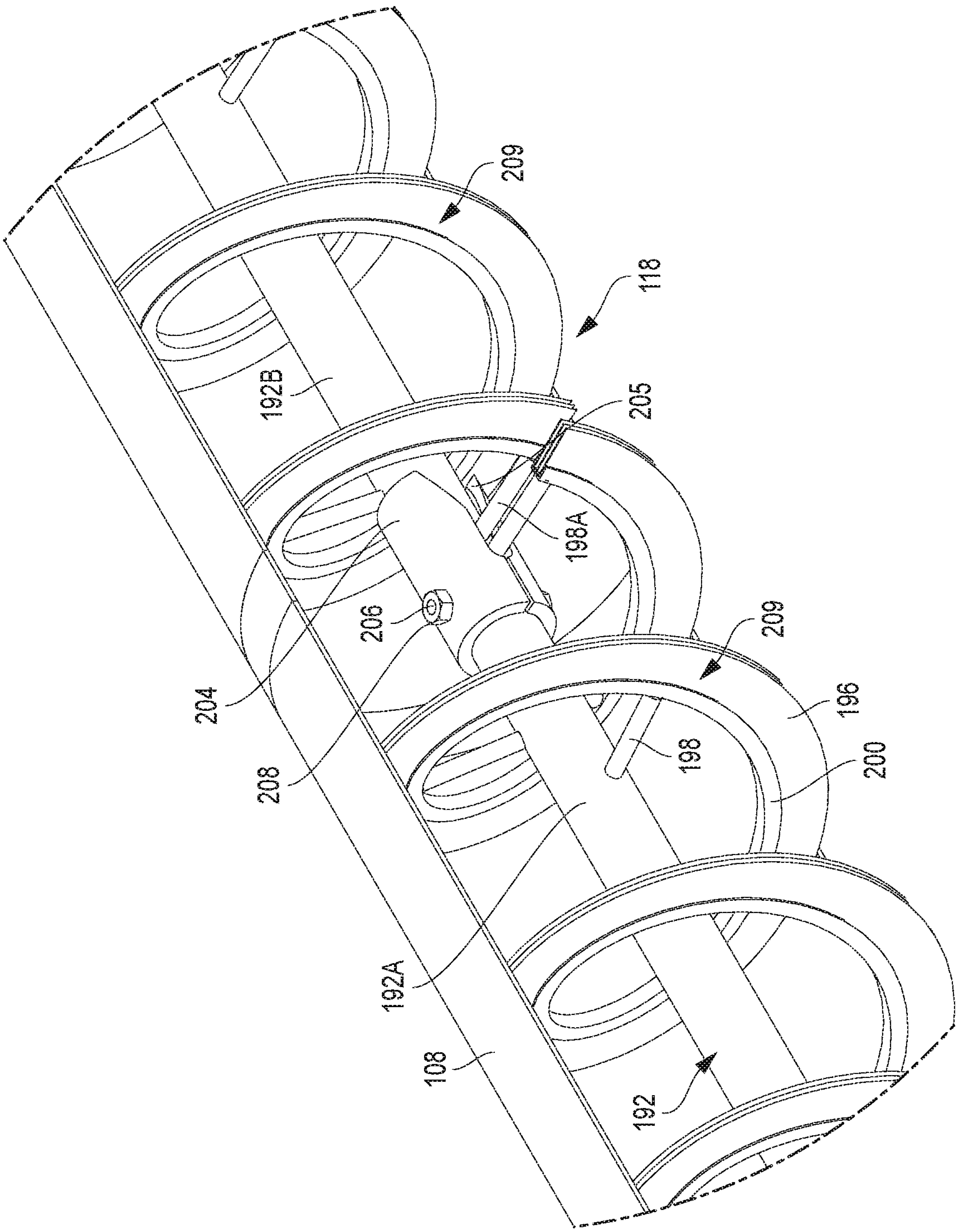

FIG. 10

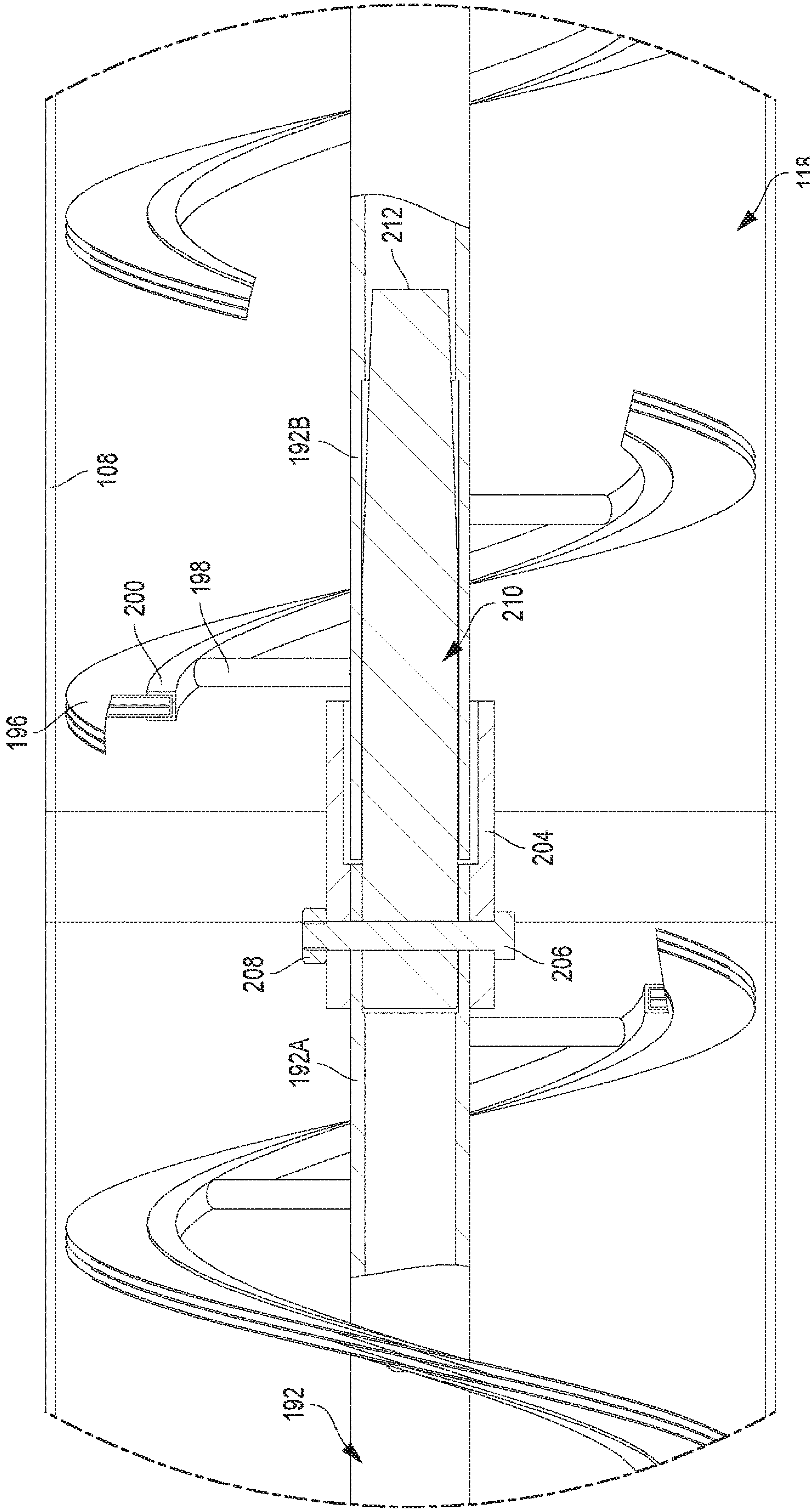

FIG. 11

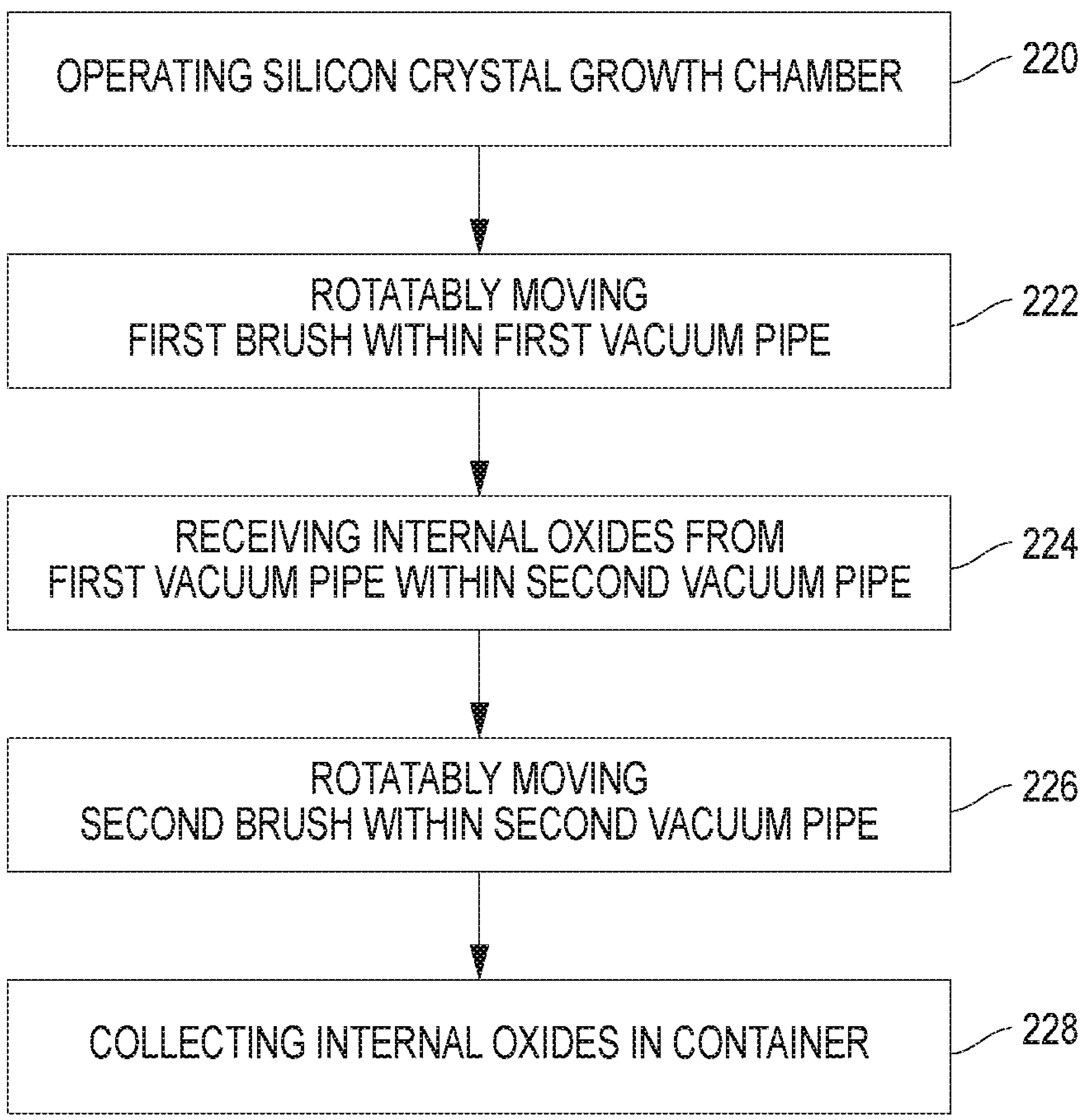
OPERATING SILICON CRYSTAL GROWTH CHAMBER
220
ROTATABLY MOVING FIRST BRUSH WITHIN FIRST VACUUM PIPE
222
RECEIVING INTERNAL OXIDES FROM FIRST VACUUM PIPE WITHIN SECOND VACUUM PIPE
224
ROTATABLY MOVING SECOND BRUSH WITHIN SECOND VACUUM PIPE
226
COLLECTING INTERNAL OXIDES IN CONTAINER
228

FIG. 12

ACTIVE CLEANING VACUUM SYSTEM AND METHOD

FIELD OF THE INVENTION

The present invention relates generally to a system for silicon crystal growth, and, more particularly, to system for removing atmosphere, including impurities, via vacuum pipes coupled to crystal growth chambers.

BACKGROUND OF THE INVENTION

Present silicon crystal growth systems require constant and often cleaning for removing impurities, including the byproduct of silicon crystal growth, i.e., silicon oxide (SiO). Typically, the cleaning process is required after each and every run of silicon crystal growth, being part of normal maintenance of a crystal grower. Problematically, current crystal growth systems require and implement a cleaning process that impedes run times for growing crystal with generally long cleanout times between runs. For example, manual intervention is required by cleaning staff after each run for thoroughly cleaning each of a plurality of main vacuum pipes. The frequency and length of each cleaning, which follows each crystal growth run, considerably delays the initiation of a next run, thus making present silicon crystal growth systems inefficient.

Thus, there is a great need for providing a cleaning system that prevents or reduces the above and other problems.

SUMMARY OF THE INVENTION

According to one embodiment of the present disclosure, a vacuum system for silicon crystal growth includes a silicon crystal growth chamber and a first vacuum pipe coupled to the chamber and having within a first brush that is movable in a first direction for removing internal oxides. The system further includes a second vacuum pipe coupled to the first vacuum pipe for receiving the internal oxides via the first brush. The second vacuum pipe has within a second brush that is movable in a second direction different from the first direction, the second brush transporting the received internal oxides away from the first vacuum pipe. The system also includes an oxides container coupled to the second vacuum pipe for receiving the internal oxides via the second brush.

According to another embodiment of the present disclosure, a vacuum system for silicon crystal growth includes a silicon crystal growth chamber operating in a vacuum environment, and a vertical vacuum pipe coupled to the chamber and including within a vertical brush. The vertical brush has a vertical bristles element that is rotatably movable around a central axis of the vertical vacuum pipe, the vertical bristles element removing deposited oxides in response to moving, frictional contact with an internal surface of the vertical vacuum pipe. The system further has a horizontal vacuum pipe coupled to the vertical vacuum pipe for receiving the oxides, the horizontal vacuum pipe including within a horizontal brush having an auger component that is rotatably movable around a central axis of the horizontal vacuum pipe. The auger component has a horizontal bristles element that makes moving, frictional contact with an internal surface of the horizontal vacuum pipe to transport the oxides along the horizontal vacuum pipe. The system further includes an oxides container coupled to the horizontal vacuum pipe for collecting the oxides received from the horizontal vacuum pipe.

According to yet another embodiment of the present disclosure, a method is directed to cleaning a vacuum system and includes operating a silicon crystal growth chamber in a vacuum environment, and rotatably moving a first brush along an internal surface of a first vacuum pipe to remove internal oxides. The first vacuum pipe has a first axis oriented in a first direction. The method further includes receiving the internal oxides from the first vacuum pipe within a second vacuum pipe. The second vacuum pipe has a second axis oriented in a second direction that is different than the first direction. The method also includes rotatably moving a second brush along an internal surface of the second vacuum pipe to move the internal oxides internally, and collecting the internal oxides in a container coupled to the second vacuum pipe.

Additional aspects of the disclosure will be apparent to those of ordinary skill in the art in view of the detailed description of various embodiments, which is made with reference to the drawings, a brief description of which is provided below.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an isometric illustration of a vacuum system for silicon crystal growth.

FIG. **2** is right side illustration of the system illustrated in FIG. **1**.

FIG. **3** is an isometric illustration of an active cleaning vacuum system of the vacuum system of FIG. **1**.

FIG. **4** is an enlarged isometric illustration of a top portion of a vertical rotating brush illustrated in "Detail **4**" of FIG. **3**.

FIG. **5** is an isometric illustration of a vertical drive mechanism for the vertical rotating brush illustrated in "Detail **5**" of FIG. **1**.

FIG. **6**A is a side illustration showing components of the vertical drive mechanism illustrated in "Detail **6**A" of FIG. **2**.

FIG. **6**B is an enlarged illustration showing a bearing wheel component of FIG. **6**A.

FIG. **7**A is a top illustration of the vertical drive mechanism illustrated in "Detail **7**A" of FIG. **2**.

FIG. **7**B is an enlarged illustration of a metal channel illustrated in "Detail **7**B" of FIG. **7**A.

FIG. **7**C is an enlarged illustration of a driven gear illustrated in "Detail **7**C" of FIG. **7**A.

FIG. **8** is an isometric illustration of a horizontal helical rotating brush and horizontal drive components illustrated in "Detail **8**" of FIG. **1**.

FIG. **9** is an isometric illustration of a horizontal pipe end and oxides container illustrated in "Detail **9**" of FIG. **1**.

FIG. **10** is an isometric illustration of a coupling joint for a horizontal helical rotating brush illustrated in "Detail **10**" of FIG. **1**.

FIG. **11** is a sectional illustration representing features of the coupling joint illustrated in "Detail **11**" of FIG. **2**.

FIG. **12** illustrates a method for cleaning a vacuum system.

While the invention is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of example in the drawings and will be described in detail herein. It should be understood, however, that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

DETAILED DESCRIPTION

Generally, an active cleaning vacuum system in accordance with the present disclosure is directed to minimizing the number of times that the main vacuum pipes of a vacuum system require cleaning, and to increasing the potential run times for cases of continuous growth. Accordingly, as described in more detail below, rotatory cleaning brushes within the vacuum pipes provide continuous cleaning of the internal diameter of the vacuum pipes. Additionally, horizontal vacuum pipes have helical (auger) brushes that both clean and transport loose oxides to a collection container. Thus, the active cleaning vacuum system eliminates or reduces the need for manually cleaning the vacuum pipes after every growth run. Instead, maintenance personnel only need to remove and empty the collection container as needed, e.g., after every growth run. The active cleaning vacuum system further reduces the frequency for manual cleaning of the vacuum pipes, which may still be required as needed.

Referring generally to FIGS. **1-3**, a vacuum system **100** for silicon crystal growth includes one or more silicon crystal growth chambers **102** that are coupled to an active cleaning vacuum system **104**. Silicon crystals are grown in the growth chamber **102** in accordance with the Czochralski Crystal Growth Process, while the active cleaning vacuum system **104** evacuates the growth chambers **102** through a series of pipes operating in a vacuum atmosphere. The cleaning vacuum system **104** removes the atmosphere within the growth environment of the growth chamber **102**, including impurities, argon purge gas, and the byproduct of silicon crystal growth, i.e., silicon oxide (SiO).

Referring specifically to FIGS. **1** and **3**, the active cleaning vacuum system **104** includes a plurality of vertical pipes **106** and horizontal pipes **108** coupling the growth chamber **102** to a plurality of oxides containers **110**. Each vertical pipe **106** has an upper end connected to the growth chamber **102** and a lower end connected to a horizontal pipe **108**, operating internally under vacuum and evacuating the atmosphere from the growth chamber **102** to the horizontal pipe **108**. The horizontal pipe **108** also operates internally under vacuum and further evacuates the atmosphere received from the vertical pipe **106** to the oxides container **110**.

In the illustrated embodiment, the vacuum system **100** includes four vertical pipes **106**, two horizontal pipes **108**, and two oxides containers **110**. On one side of the growth chamber **102**, two vertical pipes **106** are connected to a single horizontal pipe **108**, which is connected to a single oxides container **110**. On the other side of the growth chamber **102**, a similar arrangement exists, with the two horizontal pipes **108** being connected to each other via a connecting pipe **112**.

In accordance with other embodiments, the number and configuration of vertical and horizontal pipes is different, having less or more than the illustrated number of pipes. For example, in an alternative embodiment only a single vertical pipe **106** is connected to a single horizontal pipe **108**. In another alternative embodiment, three or more vertical pipes **106** are connected to the same horizontal pipe **108**. In yet another alternative embodiment, a single vertical pipe **106** is connected to two or more horizontal pipes **108**. Other configurations, consistent with the principles disclosed herein, are also captured within the teachings of the present disclosure. For brevity and clarity, the disclosure below will typically refer to a single pipe **106**, **108**, but it is understood that the disclosure applies to all similar pipes.

Additionally, in alternative embodiments the orientations of the pipes **106**, **108** is different than either vertical and/or horizontal. For example, in an alternative embodiment the vertical pipe **106** is a first pipe **106** having a first orientation (different than a vertical orientation) and the horizontal pipe **108** is a second pipe **108** having a second orientation (different than a horizontal orientation and different than the first orientation). By way of a more specific example, the first pipe **106** has an orientation inclined at a first angle ranging from 0-45 degrees relative to a vertical axis and the second pipe **106** has an orientation inclined at a second angle ranging from 0-45 degrees angle relative to a horizontal axis.

The vertical pipe **106** has a vertical rotating brush **114** that is coupled to a vertical drive mechanism **116**. The horizontal pipe **108** has a horizontal helical rotating brush **118** that is coupled at one end to a horizontal drive mechanism **120** and at another end to the oxides container **110**. The horizontal helical rotating brush **118** has at least one coupling joint **122** that separates it into at least two joined segments. Additional details are described below for each of these components.

Referring to FIG. **4**, the vertical pipe **106** contains within the vertical rotating brush **114**, which includes a plurality of channel strips **130** that are fixedly attached to a support ring **132** and that each contain a respective bristles element **134**. In the illustrated embodiment, the vertical rotating brush **114** has three channel strips **130** symmetrically positioned around the outer periphery of the support ring **132**, with each bristles element **134** having an interior end **136** contained within the respective channel strip **130** and having an exterior end **138** that makes moving contact with an internal surface **140** of the vertical pipe **106**.

The support ring **132** is concentrically aligned with a central axis Z and near a top end of the vertical pipe **106**. Additional support rings **132** are positioned along the vertical pipe **106** to provide adequate structural and operational support. For example, in the illustrated embodiment the vertical pipe **106** has a total of six support rings **132**. However, in alternative embodiments the number of support rings **132** will differ based on the length of the vertical pipe **106** and the specific support design requirements.

According to one embodiment, the components of the vertical rotating brush **114** are made entirely or in part of metal materials. For example, the support ring **132**, the channel strips **130**, and the bristles elements **134** are all made of metal. According to alternative embodiments, the components of the vertical rotating brush **114** can include non-metal materials, based on the specific requirements of a particular vacuum system.

As the vertical rotating brush **114** rotates in a direction R, the bristles elements **134** make frictional contact with the internal surface **140** of the vertical pipe **106**, resulting in the removal (e.g., scraping) of oxides **142** deposited in the internal surface **140**. Based on gravity, the oxides **142** drop down and are temporarily collected within the horizontal pipe **108**, prior to being further transported via the horizontal helical rotating brush **118** to the oxides container **110**.

Referring to FIG. **5**, the vertical drive mechanism **116** includes a vertical stepper motor **150** that is connected to a drive coupling **152**, which is in turn coupled to a magnetic fluid seal **154**. The magnetic fluid seal **154** is further coupled to a brush drive gear **156** that is interengaged with and drives a brush driven gear **158**. The brush driven gear **158** is concentrically aligned with a respective support ring **132**, mounted such that an internal surface of the brush driven gear **158** is fixed to an exterior surface of the support ring **132** via a plurality of supporting pins **160** (e.g., three pins in the illustrated embodiment). The coupling of the vertical rotating brush **114** via the supporting pins **160** allows removal of the vertical rotating brush **114** without dismantling components of the vertical drive mechanism **116**.

The vertical stepper motor **150** causes a rotation RV of the vertical rotating brush **114** around the Z axis, rotating the brush drive gear **156**, which causes the rotation of the brush driven gear **158**, which in turn causes the rotation of the respective support ring **132**. The rotation of the respective support ring **132**, which is rigidly connected to the other support rings **132** by the channel strips **130**, causes the entire vertical rotating brush **114** to rotate and clean the internal surface **140** of the vertical pipe **106**. Thus, the oxides **142** are removed from the interior of the vertical pipe **106**.

The gears **156**, **158** are enclosed within a drive gear housing **162** having a top surface **164** to which an argon gas pipe **166** is coupled. Argon gas is introduced through the argon gas pipe **166** internally into the drive gear housing **162** to maintain gear teeth of the gears **156**, **158** and respective support bearings clean of SiO. Thus, the argon gas prevents, or reduces, the binding of the gear teeth.

Referring to FIGS. **6**A and **6**B, the brush driven gear **158** is supported by one or more bearing wheels **170**, which are V-shaped and engage a V-shaped groove **172** of the brush driven gear **158**. The V-shaped groove **172** is located below and adjacent to the gear teeth of the brush driven gear **158**. According to one embodiment, the brush driven gear **158** is supported by three bearing wheels **170** located symmetrically and equidistant from each other around the Z axis (see FIG. **7**A).

Referring to FIGS. **7**A-**7**C, the brush driven gear **158** has bristles pockets **180** and pin pockets **182** for receiving respective ones of the bristles elements **134** and the supporting pins **160**. The bristles pockets **180** (shown more clearly in FIG. **7**B) are shaped and curved inward to accommodate and receive the exterior end **138** of the bristles elements **134**. Similarly, but not necessarily identically, the pin pockets **182** (shown more clearly in FIG. **7**C) are shaped and curved inward to receive an exterior end **161** of the supporting pins **160**. According to an exemplary embodiment, the bristles pockets **180** and the pin pockets **182** are machined into an internal diameter **159** of the brush driven gear **158**.

Referring to FIG. **8**, the horizontal drive mechanism **120** includes a horizontal stepper motor **184** that is connected to a first drive coupling **186**, which is in turn coupled to a magnetic fluid seal **188**. According to one exemplary embodiment and except for the horizontal orientation, the horizontal stepper motor **184**, the drive coupling **186**, and the magnetic fluid seal **188** are similar or identical to the vertical stepper motor **150** and its counterpart drive coupling **152** and magnetic fluid seal **154**.

The magnetic fluid seal **188** of the horizontal drive mechanism **120** is further coupled to a second drive coupling **190** that is connected to a horizontal support shaft **192** of the horizontal helical rotating brush **118**. The connection between the second drive coupling **190** and the horizontal support shaft **192** is made via a first support bearing **194**. The first support bearing **194** has a spherical shape and is optionally made from a resin material. The shape and/or material of the first support bearing **194** allows rotation of the horizontal helical rotating brush **118** without causing binding at the first support bearing **194** if the horizontal helical rotating brush **118** is not completely straight. The horizontal support shaft **192** is coincident with and positioned along an X axis, and is driven by the horizontal stepper motor **184**.

The horizontal helical rotating brush **118** includes a helical bristles element **196** that is directly attached to the horizontal support shaft **192** via a plurality of support spokes **198**. The helical bristles element **196** is attached to and received partially within a spiral channel **200**, which is generally similar to the channel strip **130** except that the spiral channel **200** has a spiral shape while the channel strip **130** has a straight, linear shape. The helical bristles element **196** is made entirely or partially with a metal material or with high-temperature resin bristles.

The spiral channel **200** is attached along its helix-like pitch to exterior ends of the support spokes **198**, which have interior ends attached to the horizontal support shaft **192**. The horizontal support shaft **192** has a hollow interior and acts as the spine of the horizontal helical rotating brush. When driven by the horizontal stepper motor **184**, the horizontal helical rotating brush **118** acts as an auger that rotates in an RH direction around the X axis for transporting fallen and other accumulated oxides **142** through the internal diameter of the horizontal pipe **108** to the oxides container **110**.

Referring to FIG. **9**, the horizontal helical rotating brush **118** is coupled to the oxides container **110** with an end of the horizontal support shaft **192** terminating at a second support bearing **202**. The second support bearing **202**, is optionally similar or identical to the first support bearing **194**, having a spherical shape and being optionally made from a resin material. The shape and/or material of the second support bearing **202** also allows rotation of the horizontal helical rotating brush **118** without causing binding at the second support bearing **202** if the horizontal helical rotating brush **118** is not completely straight.

The oxides container **110** collects oxides **142** and other contaminants that are received via the horizontal helical rotating brush **118**. As the horizontal helical rotating brush **118** rotates in the RH direction, the oxides **142** are being pushed by the helical bristles element **196** until the oxides **142** fall into the oxides container **110**. The oxides container **110**, as illustrated, is positioned at one end of the horizontal pipe **108** where it intersects with the connecting pipe **112**. In other embodiments, the oxides container **110** is placed in other locations deemed suitable for collecting any contaminants, including the oxides **142**.

Referring generally to FIGS. **10** and **11**, the horizontal support shaft **192** optionally consists of a primary support shaft **192**A and a secondary support shaft **192**B, which are coupled to each other via a support coupling **204** and secured in place with a support pin **206** and a support nut **208**. This feature, in which the horizontal support shaft **192** has two or more segments, is generally useful when the length of the horizontal support shaft **192** becomes too long for practically using a single segment.

Referring more specifically to FIG. **10**, the support coupling **204** wraps around and is pinned to the primary support shaft **192**A via the support pin **206** and the support nut **208**. Thus, the support coupling **204** is fixedly attached to the primary support shaft **192**A. The support coupling **204** has a tapered opening **205** that allows a respective support spoke **198**A of the secondary support shaft **192**B to engage the support coupling **204**, and thus the primary support shaft **192**A, to insure that spiral flights **209** of the helical auger are aligned between the helical bristles elements **196** supported by both the primary and the secondary support shafts **192**A, **192**B.

Referring more specifically to FIG. **11**, a pilot shaft **210** is inserted internally within the end of the primary support shaft **192**A. The support pin and nut **206**, **208**, then, fixedly secures in place the support coupling **204** to the primary support shaft **192**A and to the pilot shaft **210**. The pilot shaft **210** has a tapered end **212** for guidance of the secondary support shaft **192**B when coupling the primary and secondary support shafts **192**A, **192**B. The secondary support shaft **192**B is inserted over the tapered end **212** of the pilot shaft **210** and held in place to the primary support shaft **192**B via (a) the frictional contact between the internal surface of the secondary support shaft **192**B and the external surface of the pilot shaft **210**, and (b) the contact between the respective support spoke **198**A and the tapered opening **205** of the support coupling **204**.

Referring to FIG. **12**, a method for cleaning a vacuum system includes an operating step **220** in which a silicon crystal growth chamber is operated in a vacuum environment. The method further includes a rotatably moving step **222** in which a first brush is rotatably moved along an internal surface of a first vacuum pipe to remove internal oxides, the first vacuum pipe having a first axis oriented in a first direction. The method further includes a receiving step **224** in which the internal oxides from the first vacuum pipe are received within a second vacuum pipe, the second vacuum pipe having a second axis oriented in a second direction that is different than the first direction. The method further includes another rotatably moving step **226** in which a second brush is rotatably moved along an internal surface of the second vacuum pipe to move the internal oxides internally. The method further includes a collecting step **228** in which the internal oxides are collected in a container coupled to the second vacuum pipe.

Based on the present disclosure and for further clarity, the following are some exemplary benefits of the disclosed vacuum system and method:

- the hollow center of the support ring **132**, which is representative of a hollow core of the vertical rotating brush **114**, helps reduce bridging of contaminants, including SiO;
- the hollow interior between the horizontal support shaft **192** and the spiral channel **200**, generally defined by the length of the support spokes **198**, allows free flow of process gases along the internal diameter of the horizontal pipe **108**;
- the cleaning vacuum system **104** offers extended machine run times and shorter cleanout times between runs;
- argon gas purges components of the cleaning vacuum system **104**, such as rotating gears and bearings (e.g., brush drive gear **156**), for cleanliness;
- the vertical rotating brush **114** includes a beneficial feature in which the brush driven gear **158** is coupled to the support ring **132** via supporting pins **160** to provide ease of installation and removal;
- the horizontal helical rotating brush **118** is optionally a two-piece design with a primary support shaft **192**A and a secondary support shaft **192**B that allows for easy removal and installation;
- the two-piece design of the horizontal helical rotating brush **118** are uniquely coupled to insure alignment of spiral flights **209** (also referred to as auger blades), providing uninterrupted flow of transported oxides **142**;
- the horizontal helical rotating brush **118** is supported on its ends with spherical first and second support bearings **194**, **202** to allow the horizontal support shaft **192** to conform to the internal diameter of the horizontal pipe **108**;
- the cleaning vacuum system **104** is applicable to any form of silicon crystal growth that applies a vacuum environment;
- the cleaning vacuum system **104** is applicable to vertical, horizontal, and/or diagonal vacuum pipes;
- the rotating brushes **114**, **118** operate within the internal diameter of respective pipes **106**, **108**

According to one aspect of the present disclosure, the cleaning vacuum system **104** collects oxides **142** in two or more oxides containers **110** to reduce cleanout and/or downtime between runs. According to another aspect of the present disclosure, the vacuum system **100** is a two-port or a four-port vacuum system.

According to yet another aspect of the present disclosure, one or more of the stepper motors **150**, **184** are coupled to gear-reducing heads that have a Programmable Logic Controller ("PLC") to allow, for example, the vertical rotating brush **114** to rotate at a rate of about 4 revolutions per hour ("RPH") and the horizontal helical rotating brush **118** to rotate at a rate of about 8 RPH. This slow, controlled, speed eliminates or greatly reduces vibrations caused by the brushes **114**, **118** that could affect the stability of silicon melt in the growth chambers **102**.

The PLC control is also beneficial for obstruction detection if a stop in rotation is detected. The PLC will automatically reverse the motor direction in an attempt to un-jam the obstruction.

According to an alternative embodiment, the rotation of the brushes **114**, **118** is achieved manually, without using a motorized actuation or PLC control. For example, if needed and as applicable, the stepper motors **150**, **184** are replaced with crank handles that are manually actuated for rotating the brushes **114**, **118**.

Each of these embodiments and obvious variations thereof is contemplated as falling within the spirit and scope of the claimed invention, which is set forth in the following claims. Moreover, the present concepts expressly include any and all combinations and sub-combinations of the preceding elements and aspects. The present disclosure is not limited to the specific illustrated example but extends to alternative embodiments other shapes and/or configurations in accordance with the knowledge of one of ordinary skill in the art applied consistent with the presently disclosed principles.

What is claimed is:

1. A vacuum system for silicon crystal growth, the vacuum system comprising:

a silicon crystal growth chamber;

a first vacuum pipe coupled to the chamber and having within a first brush that is movable in a first direction for removing internal oxides;

a second vacuum pipe coupled to the first vacuum pipe for receiving the internal oxides via the first brush, the second vacuum pipe having within a second brush that is movable in a second direction different from the first direction, the second brush transporting the received internal oxides away from the first vacuum pipe; and

an oxides container coupled to the second vacuum pipe for receiving the internal oxides via the second brush.

2. The vacuum system of claim **1**, wherein the first direction is a vertical direction and the second direction is a horizontal direction.

3. The vacuum system of claim **1**, wherein the first brush is a vertical paddle brush having a hollow core for reducing bridging of the internal oxides.

4. The vacuum system of claim **1**, wherein the first brush includes a plurality of brush channels supported by a plurality of support rings, each channel of the plurality of brush channels including a respective bristles element for cleaning the first vacuum pipe in response to movingly contacting an internal surface of the first vacuum pipe.

5. The vacuum system of claim **1**, wherein the first brush is attached to an interior surface of a brush driven gear via a plurality of drive pins, the brush driven gear having an exterior gear surface coupled to a brush drive gear for rotating the first brush.

6. The vacuum system of claim **5**, further comprising a plurality of guide wheels in contact with the exterior gear surface for maintaining the brush driven gear in a level position.

7. The vacuum system of claim **1**, wherein the second brush is a horizontal helical brush having a hollow core through which process gases freely flow.

8. The vacuum system of claim **1**, wherein the second brush has an auger helical configuration that includes an internal rod supporting an auger component via a plurality of supporting pins, the auger component having an outward edge that is in movable contact with an internal surface of the second vacuum pipe, the auger component having an internal edge that is spaced from the internal rod.

9. The vacuum system of claim **1**, further comprising a stepper motor coupled to the second brush via a coupling element, the coupling element being inserted through a spherical bearing that allows flexure of the second brush relative to the stepper motor.

10. The vacuum system of claim **1**, further comprising:

a support shaft that is hollow and that supports a helical component of the second brush, the support shaft including a first segment having a first end and a second segment having a second end, the first end and the second end being adjacent to each other;

a coupling element that is hollow and within which the first end and the second end are received;

a pilot shaft inserted partially within each of the first segment and the second segment such that the pilot shaft overlaps both the first end and the second end; and

a coupling fin that secures the first end and the second end of the support shaft to the coupling element.

11. The vacuum system of claim **1**, further comprising an argon gas pipe coupled to the first vacuum pipe, argon gas flowing from the argon gas pipe through the first vacuum pipe.

12. The vacuum system of claim **1**, wherein the oxides container is directly connected to an end of the second vacuum pipe.

13. The vacuum system of claim **1**, further comprising a first stepper motor coupled to the first brush and a second stepper motor coupled to the second brush, each of the first stepper motor and the second stepper motor causing movement of a respective one of the first brush and the second brush.

14. The vacuum system of claim **13**, further comprising a first magnetic fluid seal positioned between the first brush and the first stepper motor and a second magnetic fluid seal between the second brush and the second stepper motor.

15. A vacuum system for silicon crystal growth, the vacuum system comprising:

a silicon crystal growth chamber operating in a vacuum environment;

a vertical vacuum pipe coupled to the chamber and including within a vertical brush, the vertical brush having a vertical bristles element that is rotatably movable around a central axis of the vertical vacuum pipe, the vertical bristles element removing deposited oxides in response to moving, frictional contact with an internal surface of the vertical vacuum pipe;

a horizontal vacuum pipe coupled to the vertical vacuum pipe for receiving the oxides, the horizontal vacuum pipe including within a horizontal brush having an auger component that is rotatably movable around a central axis of the horizontal vacuum pipe, the auger component having a horizontal bristles element that makes moving, frictional contact with an internal surface of the horizontal vacuum pipe to transport the oxides along the horizontal vacuum pipe; and

an oxides container coupled to the horizontal vacuum pipe for collecting the oxides received from the horizontal vacuum pipe.

16. The vacuum system of claim **15**, wherein the vertical brush includes a supporting ring that is connected to the vertical bristles element on an outer surface, the supporting ring being further rotatably movingly coupled to a stepper motor via a pair of engaging gears.

17. The vacuum system of claim **15**, wherein the horizontal brush has a support shaft that is positioned along the central axis of the horizontal vacuum pipe, the support shaft being laterally coupled to the auger component via a plurality of support spokes, the support shaft having an end rotatably movingly coupled to a stepper motor.

18. A method for cleaning a vacuum system, the method comprising:

operating a silicon crystal growth chamber in a vacuum environment;

rotatably moving a first brush along an internal surface of a first vacuum pipe to remove internal oxides, the first vacuum pipe having a first axis oriented in a first direction;

receiving the internal oxides from the first vacuum pipe within a second vacuum pipe, the second vacuum pipe having a second axis oriented in a second direction that is different than the first direction;

rotatably moving a second brush along an internal surface of the second vacuum pipe to move the internal oxides internally; and

collecting the internal oxides in a container coupled to the second vacuum pipe.

19. The method of claim **18**, further comprising actuating at least one of the first brush and the second brush with a respective stepper motor.

20. The method of claim **18**, further comprising automatically reversing a rotation of at least one of the first brush or the second brush in response to detecting an obstruction.

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